GCA Technical Report No. 63-22-N

MEASUREMENTS OF ELECTRON DENSITY PROFILE IN THE NIGHTTIME E REGION

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Paper Presented at the 1963 Spring URSI Meeting,
1 May 1963, Washington, D. C.

Contract No. NASw-489

June 1963

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Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington 25, D. C.

ABSTRACT

A series of three recent rocket flights, using a modified Langmuir probe technique, has confirmed the main structural features found in two earlier flights. The nighttime profiles differ from mid-day profiles in two main respects, (a) the E layer is irregular at night and smooth in the day and (b) the E layer is clearly separated from the F region at night by a deep trough whereas this trough is small or absent in daytime observations. A measurement at sunset showed a profile of the nighttime type though with appropriately higher values of electron density.

An intense layer of Sporadic-E was found between 98 and 102 km during the flight of Nike-Cajun 10.99 (launched 0525 EST, 7 November 1962, Wallops Island, Virginia). Comparison with the wind profile obtained 28 minutes later shows the Sporadic-E layer to be associated with a shear in the E-W component and a maximum in the N-S component. A similar relation is found for a less intense layer occurring between 120 and 122 km. Other features of the characteristically irregular nighttime E layer do not appear to be related to the wind structure.

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SECTION 1

INTRODUCTION

The observations of electron density profile were obtained on three flights made in November and December of last year (1962). The first two were made about an hour before dawn while the third was made at sunset. In each case, the measurement of the electron density profile preceded the measurement of the wind profile by the sodium vapor technique. The wind data was obtained by my collegues, E.R. Manring and J.F. Bedinger.* It was found that some features of the electron density profile are related to the wind structure, though not quite in the way that had been expected.

The measuring technique for electron density is a variation of the Langmuir probe. In the normal Langmuir probe technique, an electrode is inserted into the plasma and the current to it measured as a function of the potential of the electrode. Analysis of the current-voltage curve gives electron temperature and electron density and, in the case of rocket and satellite applications, the vehicle potential. Since each sweep of voltage (a few volts negative to a few volts positive) gives only one value of electron density the technique is somewhat limited where rapid changes are occurring. This limitation has been overcome in the present

*Under Contract No. NASw-396

instrument by keeping the electrode at a fixed (positive) potential for most of the time, interrupting this at regular intervals to sweep the potential in the manner of the normal Langmuir probe.(1) The current at fixed potential should be (and is) proportional to electron density. The only assumption made is that electron temperature is constant; the current is proportional to the average velocity of the electrons and hence varies as $(\text{temperature})^{\frac{1}{2}}$. Over the limited range of height in this investigation this appears to be a valid assumption. The proportionality of current to electron density has been verified in the flight of Nike-Apache 14.31 which carried a DC probe (as we prefer to call the instrument) and a CW propagation experiment prepared by S.J. Bauer. With the arrangement we are using (nose tip electrode) the proportionality factor is such that an electron density of 10^5 cm^{-3} produces a probe current of 10 microamp for a probe potential of 2.7 volts.

Theoretically, the Langmuir probe is limited to a collision-free plasma which would limit its use to the ionosphere above about 90 km. However, on daytime flights we have measured probe current down to 50 km and the shape of the profile strongly suggests that the proportionality of probe current and electron density is maintained in the D region.

Prior to the measurements of last November and December, we had made two daytime measurements of electron density profile using the DC probe. The most interesting feature was a Sporadic-E layer penetrated on the flight of Aerobee 4.48, Figure 1. Wallops Island ionosonde recorded

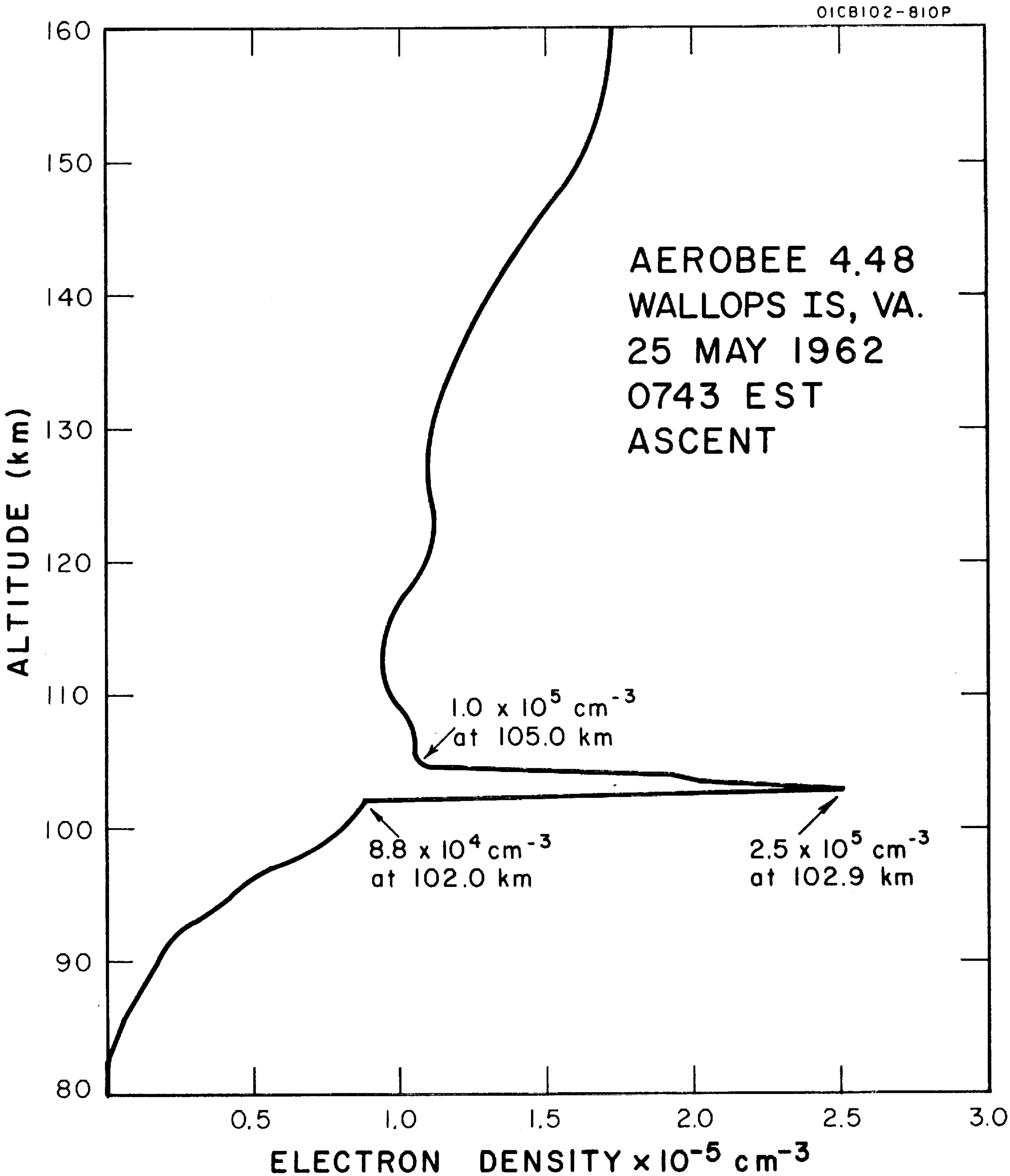


Figure 1. Electron density profile showing Sporadic E layer, 25 May 1962, 0743 EST.

at 5 min. intervals from 0600 that day and showed E_s at each observation to the end of the 5 min schedule one hour after the flight. During the rocket flight fE_s was 5.2 mc/s. As seen on the electron density profile, between 102.0 km to 102.9 km the electron density increased from 8.8×10^4 cm^{-3} to 2.5×10^5 cm^{-3}, a factor of 2.8. If this were to be explained on the basis of the equilibrium equation

$$q = \alpha n^2$$

it would be necessary to postulate that, at the peak of the layer, either (a) the rate of ionization (q) was increased or (b) the recombination coefficient (α) was decreased by the same factor of $(2.8)^2 = 8$ from what it was in the adjacent part of the E region. Either of these explanations is unacceptable. The constancy of the ionosonde echo appears to rule out a transient effect such as might be produced by a meteor. The only possible explanation seems to lie in a transport mechanism in which the plasma above the layer peak has a net downward motion and plasma below the peak has a net upward motion. (Horizontal transport is excluded because nowhere does the electron density at this height reach such large values). Several authors have pointed out that horizontal motion of the atmosphere would, in the presence of the earth's magnetic field, impart a vertical velocity to the charged particles producing a vertical transport of the plasma.[2,3] It has been shown that a wind shear in which the transport is toward the South on the low side of the shear and toward the North on the high side of the shear would result in concentration of the plasma at the altitude of zero velocity.

Two earlier rocket flights in the nighttime E region had also found Sporadic E occurring in the form of a thin layer.[4] These measurements showed in addition that at night the electron density profile up to 120 km is characterised by its irregular nature; many peaks of electron density are observed and a tendency to horizontal stratification is noted. These minor features can be regarded as weak Sporadic E layers and therefore may also be created by a wind shear mechanism. The principal objective of the series of rocket flights to be described was a determination of the role of winds in the structure of the nighttime E region with particular emphasis on the formation of Sporadic E layers.

SECTION 2

OBSERVATIONS

The technique used by Manring and Bedinger in measuring the wind structure is to release a trail of sodium vapor as the rocket ascends and photograph the trail at intervals from four well-separated ground stations.[5] At present the technique is limited to periods near sunrise and sunset when the earth's shadow is at about 85 km. Of the series of three pairs of rocket shots at Wallops Island only the first could be held for occurrence of Sporadic-E as shown on the ionosonde. The sodium rocket must be launched close to a particular time so we set the launch time for the DC probe rocket 30 minutes earlier and were prepared to "hold" for 20 minutes. The rocket carrying the probe could have been launched after the sodium rocket since it is unlikely that the sodium release would disturb the ionosphere, but it was felt that this might lead to some confusion with other rocket shots where the primary purpose has been to create an artificial ionosphere. We were prepared to try on successive days but fortunately the conditions were right on the first day and the electron density measurement preceded the wind measurement by 28 minutes.

The electron density profile is shown in Figure 2. The Sporadic E layer is about 4 km thick occurring between 98 and 102 km. The peak electron density was greater than anticipated; full scale deflection represents an electron density of 3×10^4 cm^{-3}. Beyond that point a clipping diode takes over and a very highly compressed scale results. The peak electron density in the layer, on descent, is actually about 1×10^5 cm^{-3}. The difference in layer structure on ascent and descent is interesting. The separation of the two penetrations is 67 km horizontally and about 3 min in time. The ascent shows a bifurcation of the layer with a peak density of a little over 3×10^4 cm^{-3} while on descent a single more intense layer is observed.

This profile also shows the rather irregular nature of the night-time E region noted in previous observations.(4) An upper layer occurring between 119 and 123 km should also be noted. Above this layer the electron density falls off to 950 cm^{-3} at rocket apogee (131 km).

The wind structure is shown in Figure 3 in the form of two components, North-South and East-West, magnetic. The two layers are indicated. It is seen that contrary to expectation each is associated with an East-West shear in which the motion is toward the East below the layer and toward the West in and above the layer. Shears in the opposite sense, occurring at 91 and 111 km do not correspond with any significant feature of the electron density profile. The general motion within the layers is toward the North at about 40 m/sec for the main E_s layer and toward the South at about 70 m/sec for the upper layer. The boundary of the main layer seems to be defined by the North-South component.

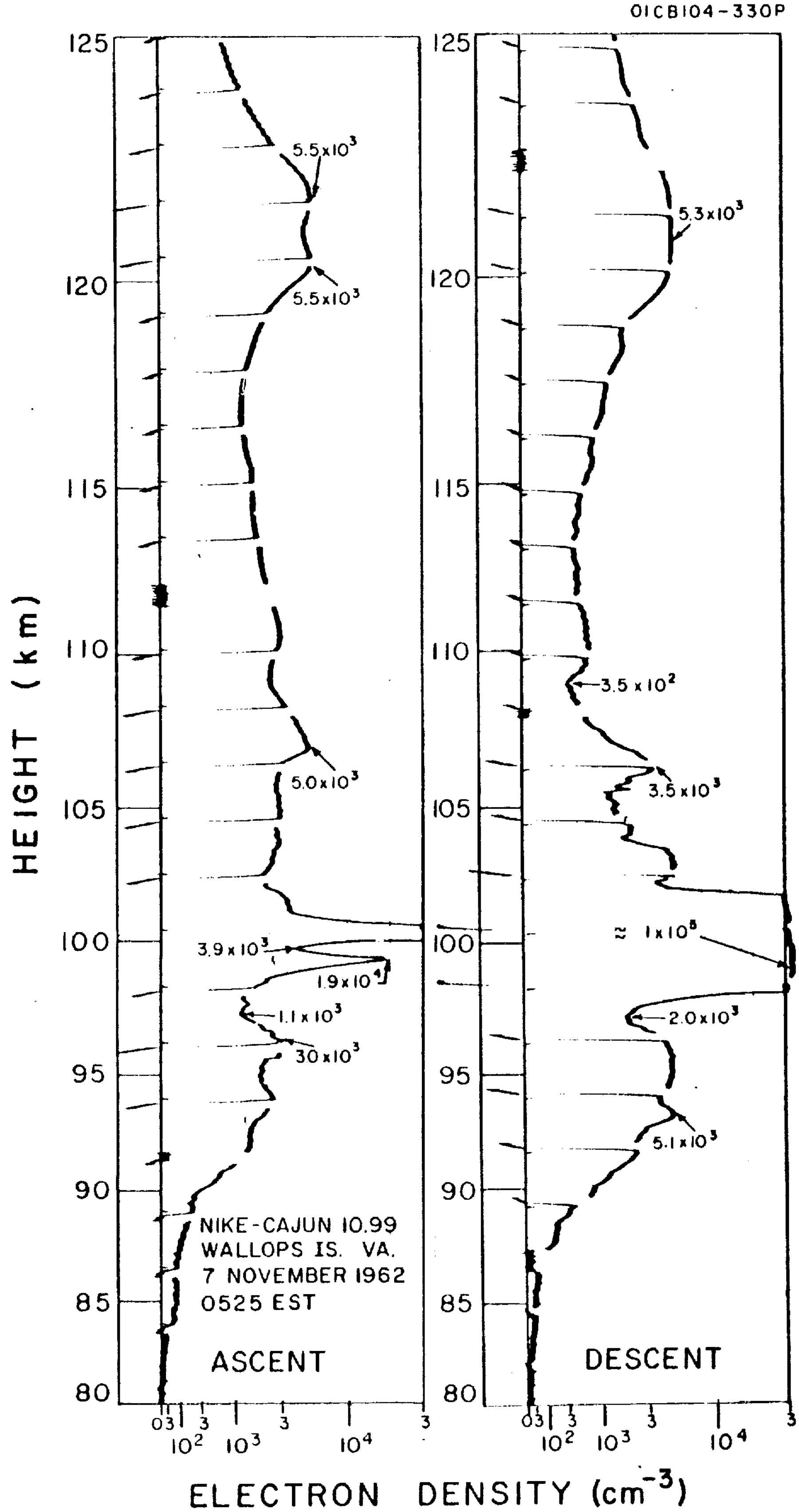
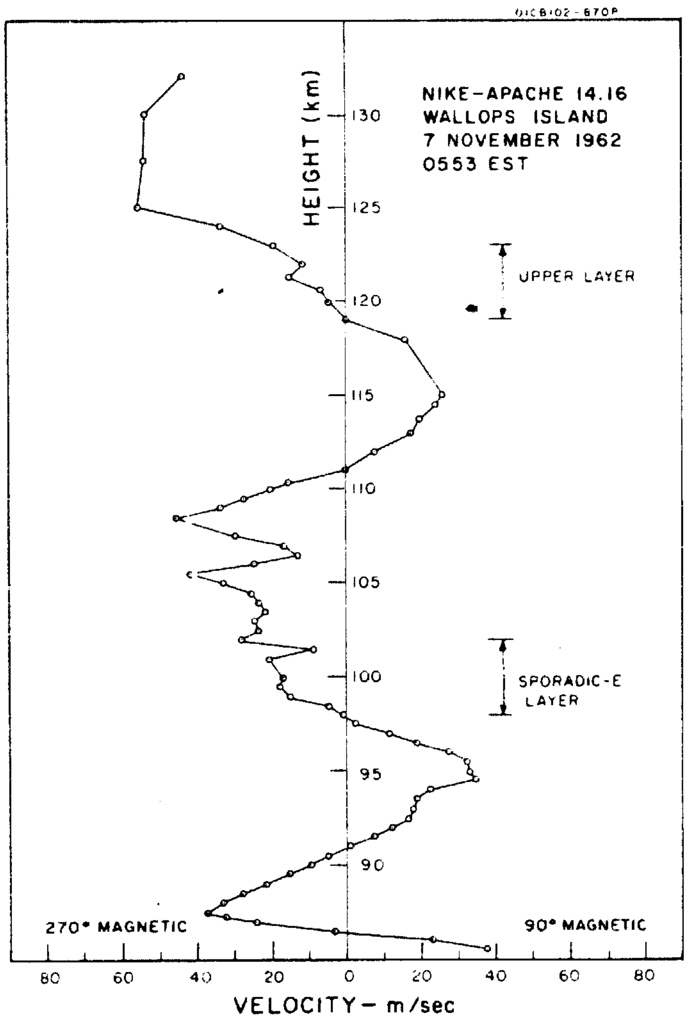


Figure 2. Electron density profiles, 7 November 1962, 0525 EST.



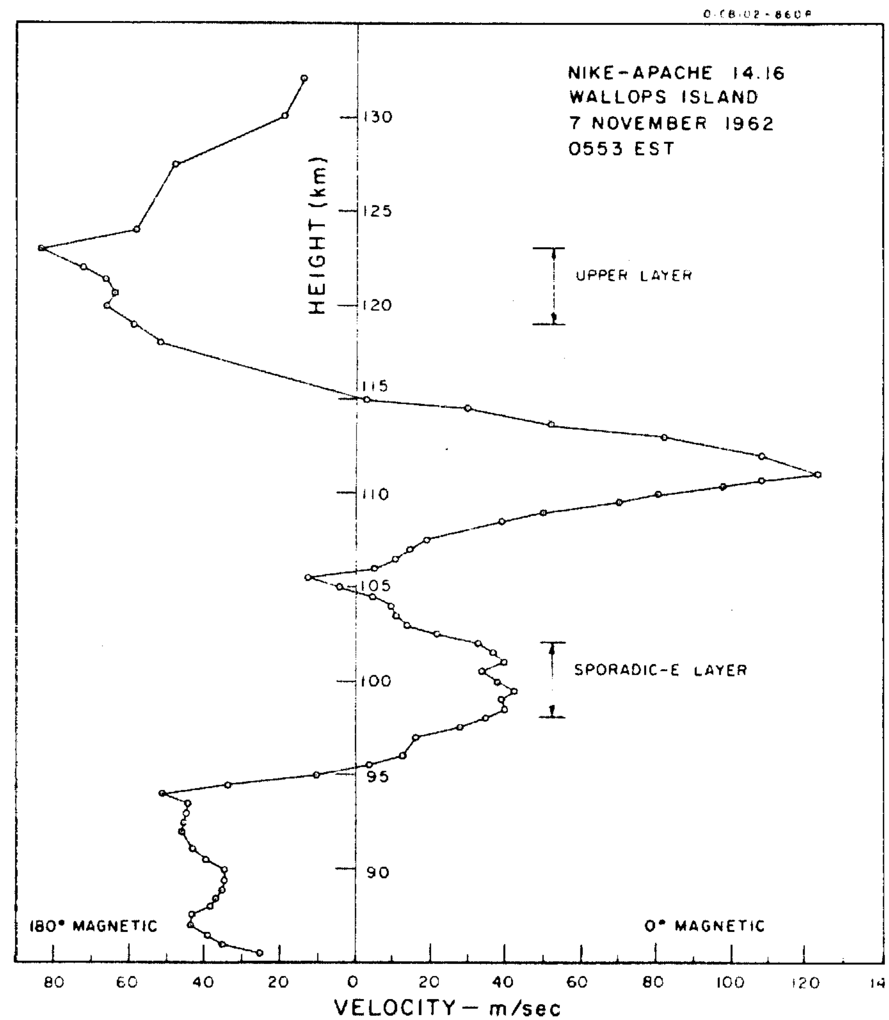


Figure 3. Wind Components, 7 November 1962, 0553 EST.

The next pair of flights were made, as it turned out, into a disturbed ionosphere. The F_2 critical frequency had dropped below 1.9 Mc/s and from 0459 to 0605 no value was recorded; the ionosonde record was in fact completely blank during the electron density flight launched at 0557. The electron density profile is shown in Figure 4. This pre-dawn profile differs noticeably from the previous nighttime observations in the scale of irregularity. The most prominent feature of the profile is a small peak at 100 km. It shows up both on ascent and descent (horizontal separation 47 km) and is regarded as a very weak sporadic E layer. Above 111 km the electron density decreases steadily to a value of 1.7×10^3 cm^{-3} at apogee (122 km) and is still decreasing.

The wind data recorded 18 minutes later, Figure 5, shows that the weak layer occurs in the same position relative to the East-West wind shear as had been noted on the previous flight. However, the previous flight had shown layers to be occurring near a maximum of the North-South component whereas this layer is located close to a minimum in the North-South component.

The third pair of flights were made at sunset. The electron density profile, Figure 6, shows the irregular structure characteristic of the nighttime E region. The horizontal separation of the profiles at 100 km altitude is 72 km. The lack of correspondence between the two profiles in the height range 108 to 118 km is unusual. The peak values of electron density on ascent and descent are about equal (9.4×10^4 cm^{-3} and 8.9×10^4 cm^{-3}) but the heights do not correspond. A similar lack of correspondence was found in the height range 101 to 107 km on an earlier flight (Nike-Cajun 10.52).

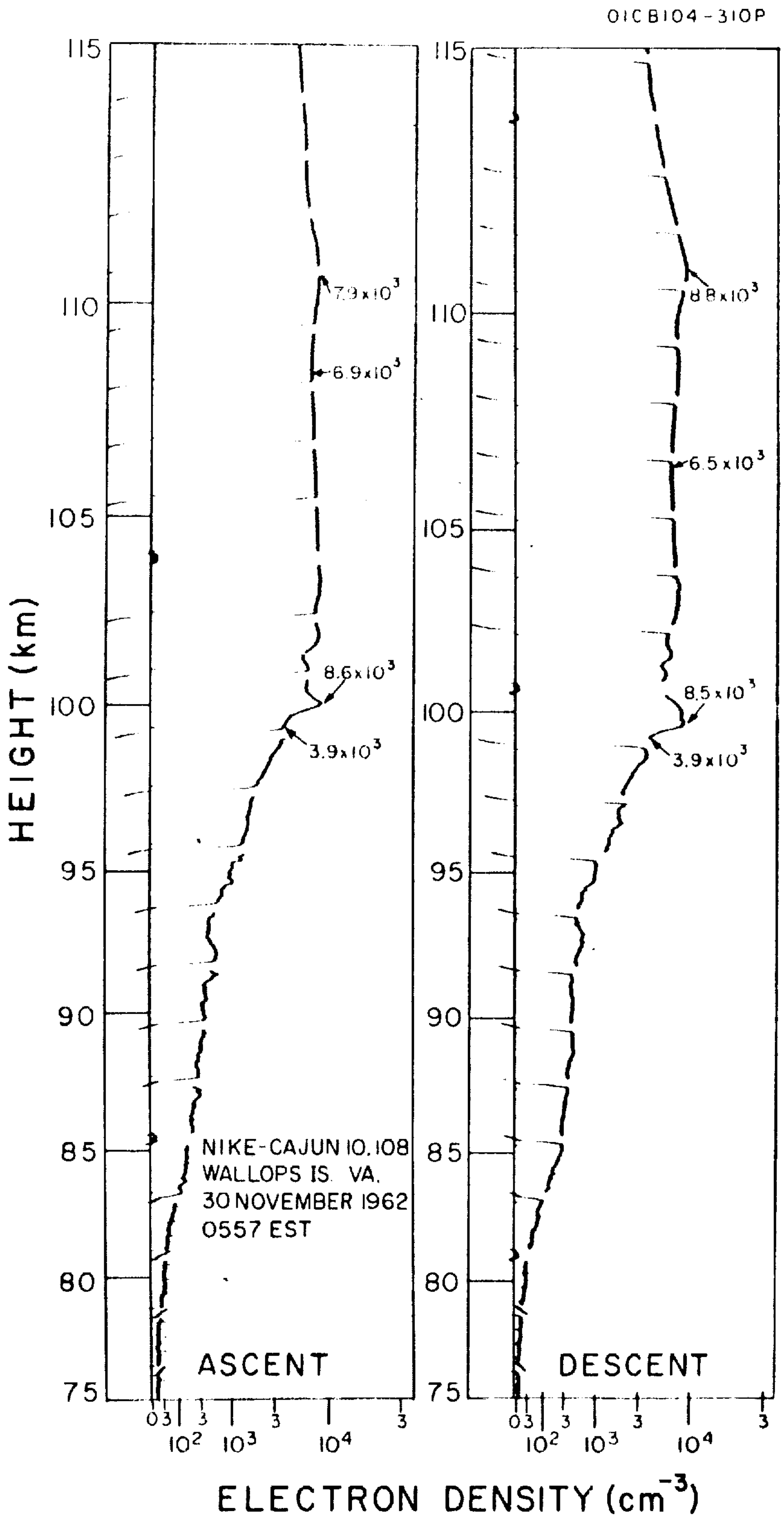


Figure 4. Electron density profiles, 30 November 1962, 0557 EST.

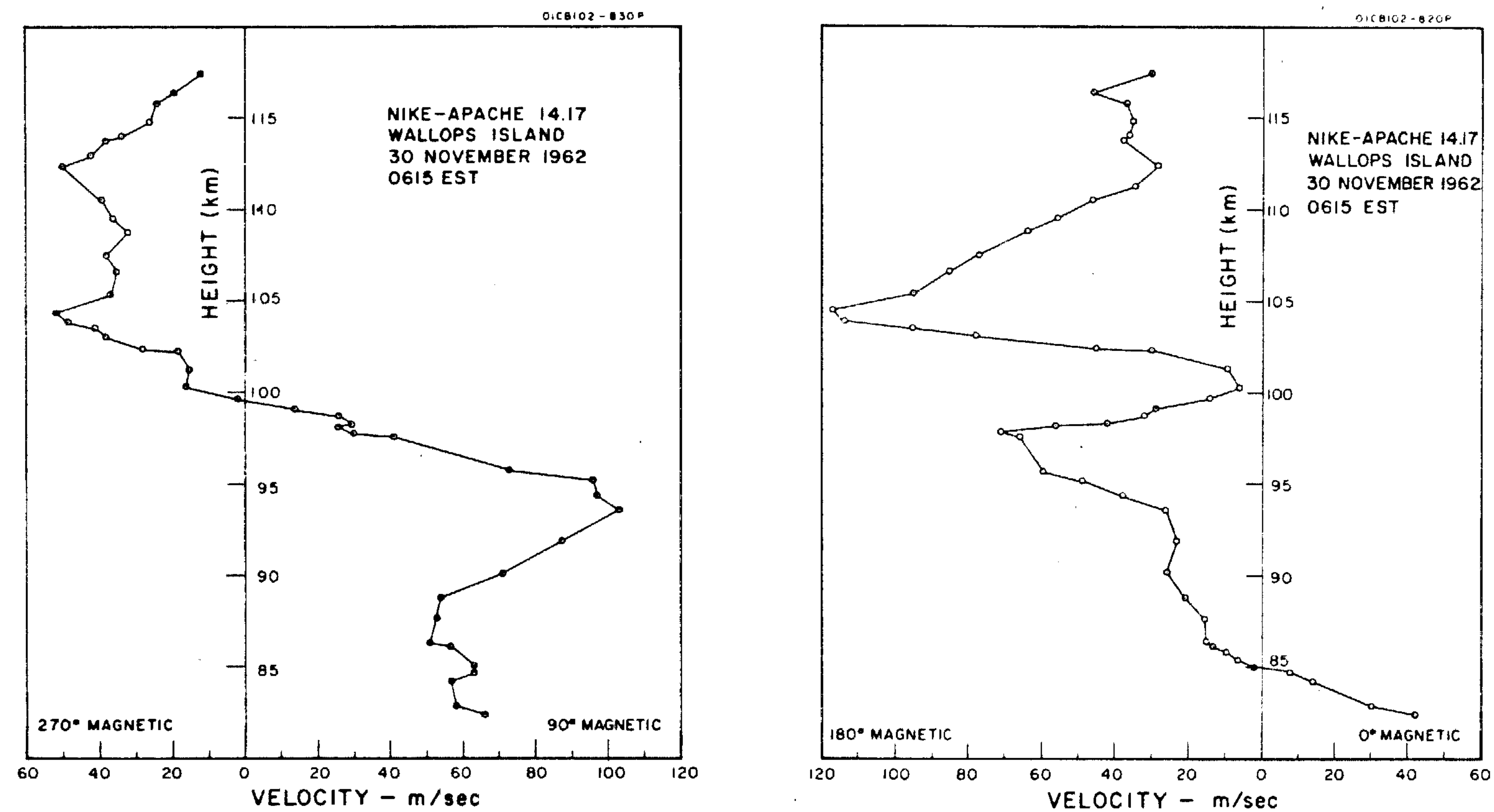


Figure 5. Wind Components, 30 November 1962, 0615 EST.

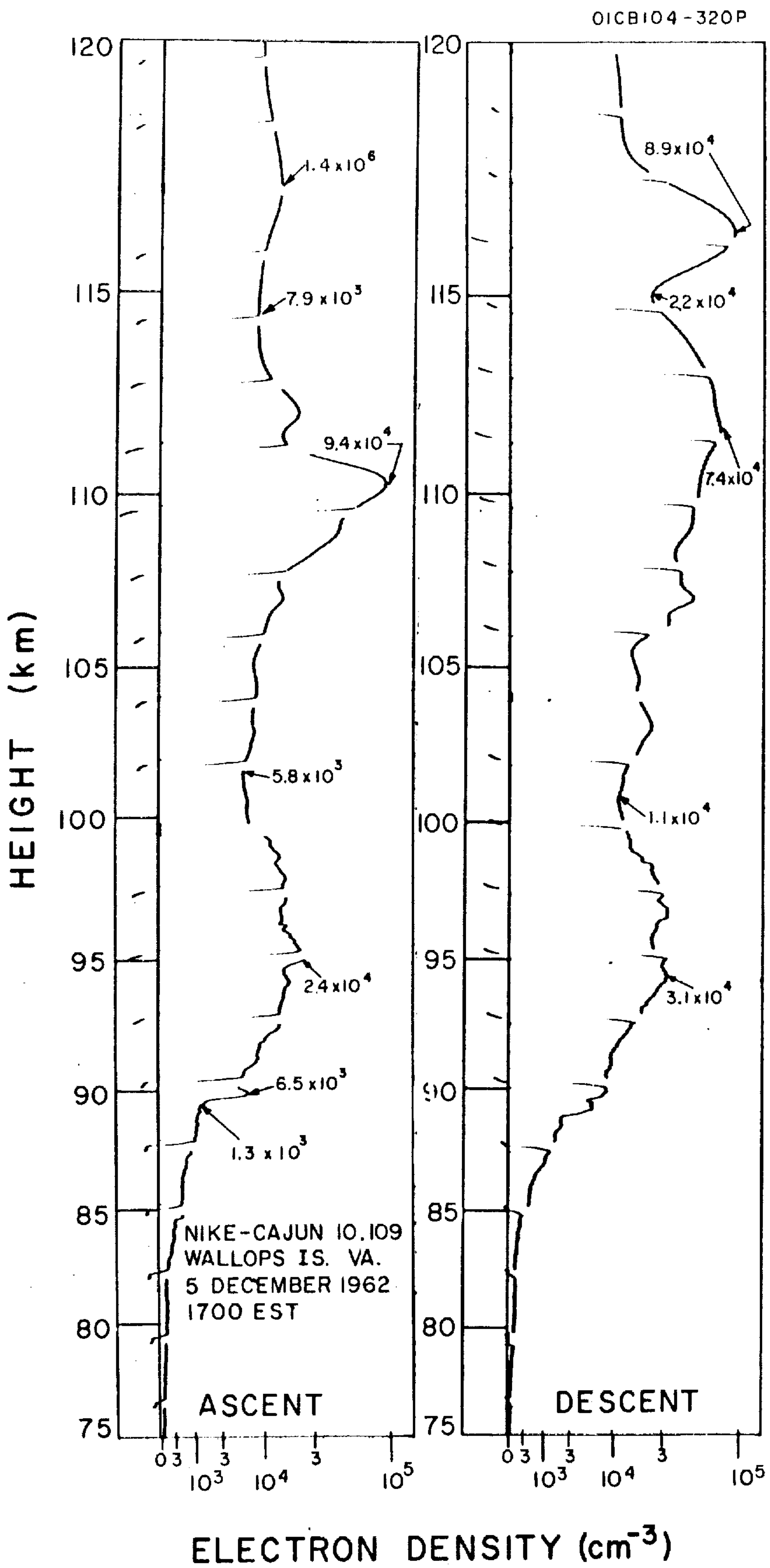
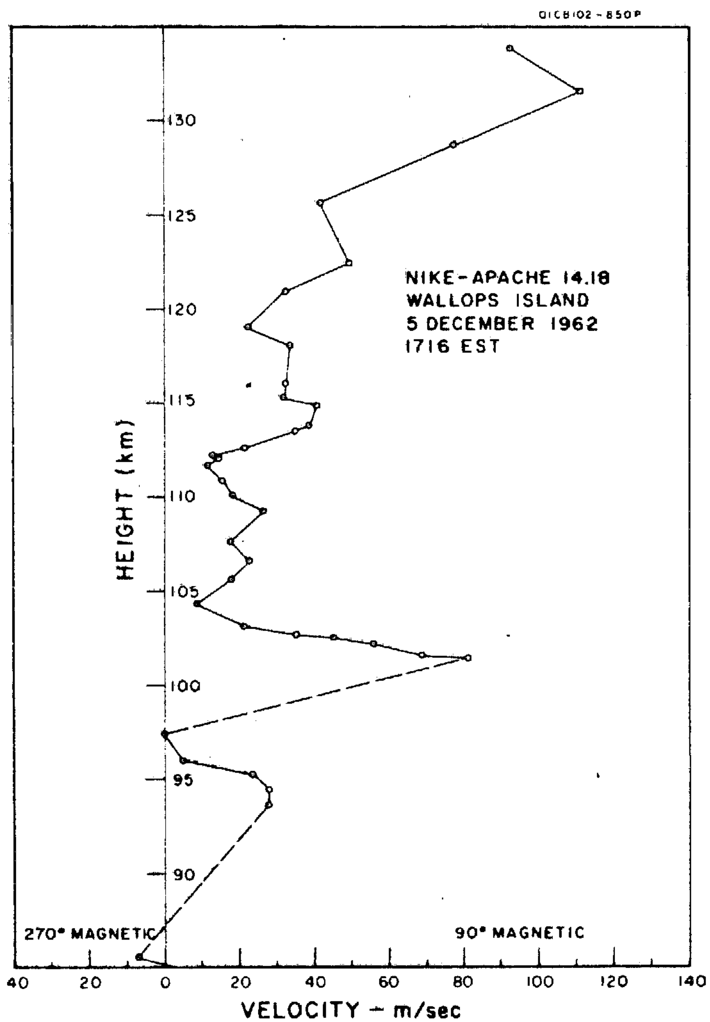


Figure 6. Electron density profiles, 5 December 1962, 1700 EST.

Sporadic E was recorded by the ionosonde during the flight with a maximum frequency fE_s ranging from 7.7 Mc/s to 9.6 Mc/s. The virtual height was recorded as 110 km. This agrees in height with the largest peak on the ascent profile but in view of the absence of a corresponding peak on the descent profile it is not established that this was the feature producing the sporadic E echo.

At rocket apogee (128 km) the electron density was found to be $6.3 \times 10^{3} cm^{-3}$ which may be compared with a value of about $1 \times 10^{3} cm^{-3}$ in the pre-dawn measurements and about $1 \times 10^{5} cm^{-3}$ in daytime profiles.

The wind components, obtained 16 minutes later, are shown in Figure 7. Due to poor visibility parts of the profiles are missing (dashed lines). The East-West profile is unusual in that it does not show any shears crossing the axis. The features of the electron density profile, either ascent or descent, cannot be identified with features on the wind profile.



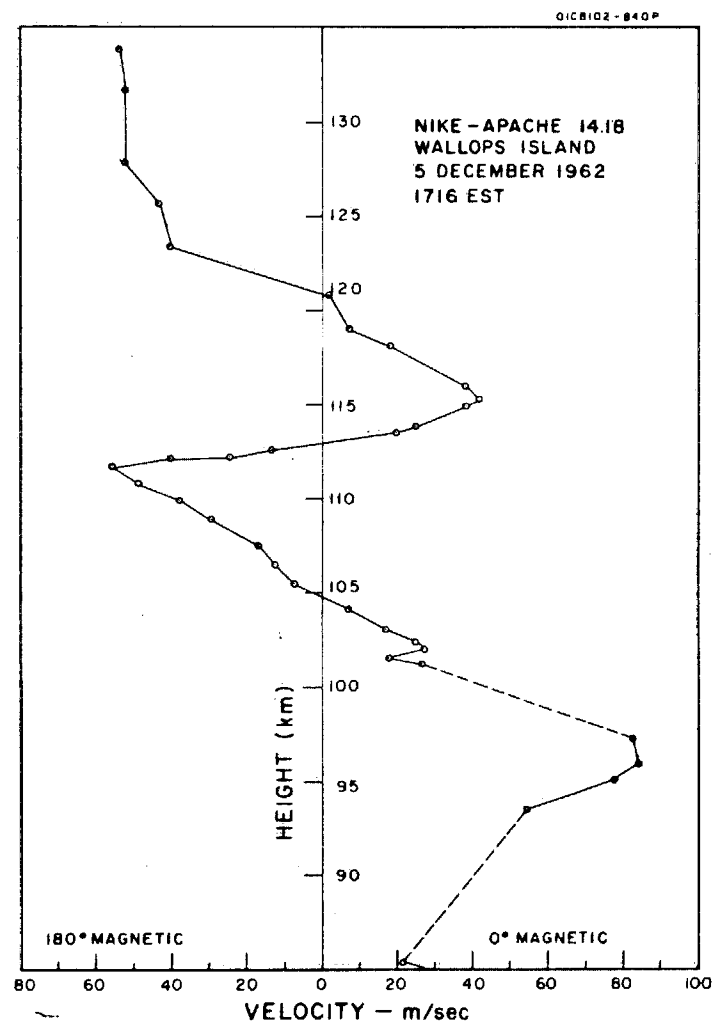


Figure 7. Wind Components, 5 December 1962, 1716 EST.

SECTION 3

CONCLUSIONS

Two features characterize the structure of the nighttime E region. The first is the deep trough which separates the E and F layers at night. The lower boundary of this trough occurs at about 125 km. By dawn the electron density in this region has fallen to several hundred per cm^3.

The second feature is the general irregularity of the nighttime E layer. Its variability from one night to another is in marked contrast to the regular behaviour of the daytime E layer.

The electron density profile obtained at sunset also shows irregular structure characteristic of the nighttime profiles. This was quite unexpected and indicates that a rapid change in structure occurs in the late afternoon.

In view of the generally irregular nature of the region at night and the marked stratification the identification of Sporadic E layers is more difficult than in the daytime profiles. However, the height of occurrence is most often within a few kilometers of 100 km. The three most intense cases we have observed have peaks at 102.5 km (Nike-Cajun 10.51, night), 102.9 km (Aerobee 4.48, day) and 99.5km, (Nike-Cajun 10.99, night). Seddon [6] has reported cases with peaks at 100.9 km (Aerobee NRL-50, day) and 98 km (Aerobee NN3.11F, night) and quotes a nighttime observation of H. S. W. Massey showing a peak at 100.5 km. This narrow range of height (98-103 km) distinguishes Sporadic E from the less pronounced ledges and layers which are commonly found on the electron density profile up to 90 km in the day and up to 120 km at night.

Comparison of the electron density profiles with the wind observations has indicated a definite relation in layer formation. The particular feature of the wind profile is a shear in the East-West component in which the motion is towards the East on the low side and toward the West on the high side. Three examples of this type of shear (above 90 km) each gave rise to a layer. On the flight of 7 November 1962 such a shear at 98 km produced an intense Sporadic E layer while a comparable shear at 119 km produced a rather weaker layer. On the flight of 30 November 1962 the shear at 99.5 km produced a minor layer. No shear of this type was observed on the flight of 5 December 1962, nor did the electron density profile contain a clearly identifyable Sporadic E layer. However the ionosonde was indicating strong Sporadic E. This must be regarded as an anomalous case neither supporting nor disproving the relation which was indicated in the previous measurements.

It is interesting that each of the three layers is centered somewhat above the point of zero velocity indicating a net motion to the West. This combines with the North-South component to determine the actual motion of the layers.

The role of the North-South component of wind is not clear. In the case of the intense Sporadic E layer of 7 November 1962 it appears to define the boundaries of the layer.

The simple experimental techniques used in this project have established the feasibility of direct measurement Sporadic E and have indicated a definite relationship with winds. Further measurements, more nearly simultaneous, are required to difinitely establish this relationship and to determine what other features, if any, of the electron density profile are related to wind structure.

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